CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-229

MALIBU COAST FAULT
LOS ANGELES COUNTY, CALIFORNIA

by

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State of California
Department of Conservation

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FIGURES

PREFACE

Since the initial preparation of this report there have been two revised references and two additional references that have come to our attention.

The Dibblee Foundation has published the Malibu Beach and Point Dume quadrangles (Dibblee, 1993; Dibblee and Ehrenspeck, 1993) with minor revisions relative to the preliminary maps used in our initial review. Changes relevant to this evaluation involve slight relocations of some of the fault traces. These changes have not been incorporated into Figures 3b and 3c, but can be identified by comparison with the now-published Dibblee Foundation maps. The relocation of some fault traces has no impact on the recommendations included in this report.

Dill Geomarine Consultants (1993) has made an offshore survey about three miles east of this study area. In their survey they have interpreted a pair of possible offshore faults, but found no evidence of Holocene displacement. There is insufficient date to determine if these inferred offshore faults connect with any of the onshore faults evaluated in this Fault Evaluation Report.

The study by Leighton and Associates, Inc. (1994) investigated the continuity of subsurface deposits in the Malibu Civic Center area (west of Malibu Creek and north of the Pacific Coast Highway/Highway 1). They found no evidence of fault displacement and concluded that there have been no significant Holocene displacements along the Malibu Coast Fault in this locality.

ADDITIONAL REFERENCES

Dibblee, T.W., Jr., 1993, Geologic map of the Malibu Beach quadrangle, Los Angeles County, California: Dibblee Geological Foundation Map #DF-47, 1:24,000.

Dibblee, T.W., Jr., and Ehrenspeck, H.E., 1993, Geologic map of the Point Dume quadrangle, Los Angeles and Ventura Counties, California: Dibblee Geological Foundation Map #DF-48, 1:24,000.

Dill GeoMarine Consultants, 1993, Castellammare offshore seismic survey, Santa Monica, California: unpublished consultant's report, August 14, 1993, 22p.

Leighton and Associates, Inc., 1994, Report of geotechnical studies for planning purposes in the Civic Center area, City of Malibu, California: unpublished consultant's report, Project No. 2920647-01, March 18, 1994, two volumes.

PURPOSE

Figure 1a. Location of study area.

The purpose of this evaluation is to determine if any strands of the Malibu Coast fault zone are sufficiently active and well-defined to warrant zoning under the Alquist-Priolo Earthquake Fault Zoning Act (Hart, 1994). The Malibu Coast fault zone is an important east-west trending, north-dipping reverse fault zone which probably has also had significant left-lateral displacement. The fault zone demarcates the southern margin of the western Santa Monica Mountains for approximately 25 miles along the Malibu Coast and also separates different geologic terrains. It is a splay of a 150-mile long system of faults, including the Santa Cruz Island, Anacapa, Santa Monica, and Raymond fault zones, which form part of the southern margin of the western Transverse Ranges structural province (Figure 1b). The Malibu Coast fault was previously reviewed in Fault Evaluation Report 46 (Smith, 1977), which recommended no zoning. Recent findings of probable Holocene displacement at two localities along the fault zone prompted the California Division of Mines and Geology to re-evaluate the fault for possible inclusion in an Alquist-Priolo Earthquake Fault Zone.

SCOPE OF INVESTIGATION

This report assesses the evidence for recency and continuity along the various onshore Quaternary strands of the Malibu Coast fault zone as identified on the Triunfo Pass, Point Dume and Malibu Beach 7½ minute quadrangles. The study area considered in this evaluation is shown on Figures 1a and 1b.

DATA SOURCES

Early work on the Malibu Coast fault zone was reviewed by Smith (1977). He found that there was no evidence at that time for Holocene displacement along the fault. The principal mapping of the onshore fault zone (at a scale of 1:12,000) was done by geologists of the U.S. Geological Survey in the 1960's and early 1970's (Yerkes and Wentworth, 1964 & 1965; Wentworth and Yerkes, 1965; Campbell, 1968; Campbell and others, 1970; Yerkes and others, 1971 & 1973). Some of this work has since been published at 1:24,000 (Yerkes and Campbell, 1980). An alternative interpretation of the geology and faulting has been made by Dibblee and Ehrenspeck (1990; 1990-92). Interpretations or summaries of offshore faulting have been shown by Greene and others

(1975), Jennings (1975), Junger and Wagner (1977), Yerkes and Lee (1979), Greene and Kennedy (1986), and Ziony and Jones (1989). Recency of faulting, both onshore and offshore was summarized several years ago by Ziony and others (1974) (see Figure 2a). The general geology of the Santa Monica Mountains has been discussed by Durrell (1954) and by Dibblee (1982).

Other recent work has been principally by various consultants for site-specific projects. All known work where faulting has been identified has been cited in the references and/or included in Table I. Aerial photographs used for this study are identified on page 35.

REGIONAL OVERVIEW - TECTONIC SETTING, GEOMORPHOLOGY and SEISMICITY

The Malibu Coast fault zone is within a larger transpressive zone of north-dipping left-lateral, reverse-oblique faults that control the southern boundary of the Transverse Ranges. The major faults of this zone (Figure 1b) are, from the west, the Santa Rosa Island fault, the Santa Cruz Island fault, the Anacapa fault (also called the Dume fault), the Santa Monica fault and the Raymond fault (Junger and Wagner, 1977; Pinter and Sorlien, 1991). Since early Miocene time the western Santa Monica Mountains have been rotated nearly 80° clockwise, accompanied by as much as 60 km of left slip along the range-bounding fault system (Hornafius and others, 1986). Although strike-slip displacement, principally along the proto-Malibu Coast fault, may have been dominant in the fault zone's early history, by Pleistocene time north over south compression was the dominant force (Campbell, 1990). The late-Quaternary uplift rate along the Malibu coast has been approximately 0.3mm/yr (Lajoie and others, 1979). Left-lateral displacement has probably continued, in a diminished sense, as a component of the total strain, as suggested by numerous stream deflections and locally observed striae in fault gouge. Whereas the Malibu Coast fault was, in the past, a major tectonic boundary, the Anacapa fault has apparently taken over as the major province-bounding feature. This migration of tectonic activity outward from the main mountain front is similar to what Bull (1987) described along the front of the San Gabriel mountains. To the west, the left-lateral Santa Cruz Island fault has been shown to be active within the past 11.78 ±0.1 thousand years (Pinter and Sorlien, 1991). To the east, the Raymond fault has also been shown to have had Holocene displacement (Crook and others, 1987); historic seismic activity indicates left-lateral displacement (Jones and others, 1990).

The Malibu Coast fault zone is usually shown as a separate element of the southern Transverse Ranges boundary faults, distinct from the Anacapa and Santa Monica faults (Yerkes and Lee, 1979; Ziony and Jones, 1989). While the Anacapa fault actually marks the southern boundary of the Transverse Range province, the Malibu Coast fault separates different stratigraphic sequences within the Transverse Ranges (Junger and Wagner, 1977, Campbell, 1990). Junger and Wagner (1977) considered the Malibu Coast fault to be a northern branch of the Santa Monica fault zone. McGill (1980) states that the Potrero Canyon fault, (east of the study area, near Santa Monica, see Figure 2a), is probably an onshore extension of the Malibu Coast fault zone and Campbell (1990) shows this connection as well, but offshore data to prove this connection are lacking. The eastern end of the study area coincides with the eastern mapped extent of the Malibu Coast fault zone; its connection to other faults to the east is undetermined. Jim Dolan and Kerry Sieh, at CalTech, are currently conducting research on the Santa Monica fault and further evaluation of that fault zone will await the conclusion of their studies.

The Potrero Canyon fault is considered to be part of the Santa Monica fault zone (Dolan and Sieh, 1992), probably a north branch as suggested by Junger and Wagner (1977) and by unpublished work by Robert L. Hill (California Division of Mines and Geology). A south branch of the Santa Monica fault probably extends offshore to the Anacapa fault, either as shown by Hill (1979) or by Junger and Wagner (1977) and Yerkes and Lee (1979). Greene and Kennedy (1986) show Quaternary and even Holocene displacement along a few portions of the offshore Anacapa-Santa Monica fault. They also show an offshore Holocene fault which they project onshore near Paradise Cove (Point Dume quadrangle) near where Campbell and others (1970) show a queried fault. This fault, which Greene and Kennedy (1986) have labeled also the Malibu Coast fault, is queried eastward and is not extended by them onshore to the Santa Monica fault.

Associated geographically with the Malibu Coast fault zone are several older thrusts (generalized but not named on Figure 2a) that have been mapped to the north, within the upper block of the fault zone (Campbell and others, 1966; Yerkes and Campbell, 1980). The Tuna Canyon, Zuma, and Malibu Bowl thrust sheets are believed to be late middle Miocene in age and are deformed and cut by later events, including faulting along the Las Flores thrusts. The Las Flores thrust faults were later intruded by volcanics. These earlier faults were not part of the Miocene stike-slip Malibu Coast fault and are not considered here as part of the more recently active fault zone. The Malibu Coast fault postdates all of these earlier faults although some late Pleistocene "adjustments" have occurred along the older faults, particularly east of Topanga Canyon (to the east of the study area)(Campbell and others, 1966; McGill, 1989). These displacements are scattered and involve deposits over 100,000 years old. McGill (1989) states that "such displacements do not represent extensive reactivation of these late middle Miocene detachment faults, but were local, relatively minor adjustments to late Quaternary stresses at places where the old surfaces of weakness were favorably oriented." In the vicinity of Pepperdine University an isolated piece of the Malibu Bowl fault may have been absorbed into the Malibu Coast fault zone and accommodated some late-Pleistocene displacement.

Campbell (1990) has observed that many of the late Pleistocene displacements along the fault zone do not fall along the main fault trace. In the area considered in this evaluation (the Triunfo Pass, Point Dume and Malibu Beach quadrangles) most of the late Pleistocene displacements recorded are between the main trace of the Malibu Coast fault and the Anacapa fault to the south. These young displacements principally involve post-Stage 7 or 5e (roughly 200,000 to 124,000 years or younger) terrace deposits, with only two localities documenting possible Holocene displacement. Some displacements are older.

The terraces on which age of faulting is gauged were mapped and distinguished in part by Yerkes and Wentworth (1965) and later by Birkeland (1972) who assigned slightly younger ages to the terrace platforms. The main terraces mapped were designated the Dume terrace, the Corral terrace and the Maibu terrace. Yerkes and Wentworth (1965) dated the Dume terrace at 120,000 years and the Corral terrace at 280,000 years with the Malibu terrace being still older. Birkeland cited average ages for the Dume and Corral terraces of 104,000 years and 131,000 years, respectively. The terrace deposits have been mapped since in more detail (Campbell and others, 1970; Yerkes and Campbell, 1980), with regard to extent and location, but their work did not specifically describe or refine the relative age of the terrace deposits. Lajoie and others (1979), support the general age assignments of Yerkes and Wentworth (1965), pegging the Dume terrace at 124,000 (marine oxygen isotope stage 5e) based on the presence of warm water fauna at Point Dume which correlate the deposits with established stage 5e terraces elsewhere. The Corral terrace (isotope stage 7) is probably about 200,000 years old. The correlation of the various mapped terraces is reasonably clear west of Solstice Canyon, but to the east the assignment of the terraces to a specific age or isotope stage is less certain.

Geomorphology

Gross geomorphic features, although suggesting Quaternary displacement, provide no evidence of Holocene fault activity. The most prominent features that may be fault related are a series of apparent 2000' to 3000' left-lateral deflections of several of the more prominent canyons from Ramirez Canyon (on the Point Dume quadrangle) to Puerco Canyon (on the Malibu Beach quadrangle). These are shown on Figure 4a. Four deflected canyons are obvious and two other, now beheaded, deflections might be inferred. Yerkes and Wentworth (1965) point out that three of the four clear deflections do not correspond with the main trace of the Malibu Coast fault. They do, however, fall along the main trace as mapped by Dibblee and Ehrenspeck (1990-92). Paradoxically, the two largest and presumably oldest canyons, Zuma Canyon and Malibu Canyon, do not show obvious corresponding deflections. Although Zuma Canyon is not obviously deflected it may have once drained through one of the shorter canyons over to the east side of Point Dume, such as Walnut Canyon (a deflection of 2000 to 4500 feet). There are also two points where Zuma Canyon narrows abruptly at faults mapped by Campbell and others (1970) [the northern trace] and by Dibblee and Ehrenspeck (1990) [the southern trace]. This would suggest a vertical component of displacement, although differential resistance of bedrock units can also explain the narrowing of the canyon. There also is no significant onshore deflection of Malibu Canyon, however the canyon does widen dramatically (in a right-lateral sense) at the coastline. Any offset of the canyon, however, may have been removed by coastal erosion.

Yerkes and Wentworth (1965, p.148) stated that the deflections could be principally a result of lithologic control behind resistant bodies of Monterey Shale. They suggest that the left deflections may have been initially influenced, perhaps, by spits built by eastward directed longshore drift along an ancient higher and landward shoreline and then subsequently entrenched as the terrace was uplifted.

Dibblee (1982) also noted the major deflections, as well as several smaller deflections along the western part of the fault zone. A plot of the major and minor drainages against the fault pattern (Figure 4b) reveals some uncertainty in the consistency of the offsets. Although some drainages do show variable left-deflections, some left-deflections are not aligned with the mapped fault traces, some show right-deflections, and some show none at all. Again, as with the larger deflections to the east (Figure 4a) the largest drainages show no deflection (Figure 4b, notes 1, 2, 3, & 13) or ambiguous deflections (notes 5, 12, 16, 19 & 20). San Nicholas, Los Alisos and Lachusa Canyons (notes 1,2 & 3) are entrenched into the Dume terrace (124,000 year old) without any deflection, indicating the lack of any significant near-Holocene displacement at these locales.

As indicated by Campbell (1990), left-lateral displacement occurred in the early history of the fault zone through the Pliocene, although data indicate that a component of lateral displacement has continued. The deflected drainages are incised into the mid- to late-Pleistocene landscape (Figure 4a), suggesting a long-term average lateral slip-rate on the order of 1-2 mm/yr. Lesser deflections in the pre-124,000 year old terrace (Figure 4b) of up to 300' to 400' suggest a late-Quaternary slip-rate of up to 0.5 mm/yr. The lack of any detectable deflection in younger streams suggests that this process is now at a minimum. Although left-lateral displacement has probably continued as a component of the total strain, it may have been distributed throughout the fault zone rather than manifesting itself as left-slip along one continuous well-defined fault.

Another prominent feature is the abrupt elevation change along the mountain front. It might be inferred that this front is the result of uplift along a major fault zone. Yerkes and Wentworth (1965, p.148-150), however, discussed this relatively abrupt mountain front and concluded that it was most likely a product of marine erosion rather than differential tectonic uplift. Although the elevation of the range is almost certainly due to tectonic influences, the abruptness of the front is probably more a result of marine erosion being limited by the band of resistant Monterey formation and volcanic units. Yerkes and Wentworth (1965) stated, however, that if the front were a result of faulting then it is "considerably modified" by erosion and the faulting must predate the terrace which crosses the Malibu Coast fault west of Malibu Canyon (124,000 to 200,000 year old Dume or Corral terrace) and further west, on the Triunfo Pass quadrangle (Figure 3a; probably the 124,000 year old Dume terrace), without a similar elevation change. The fact that the abrupt front seems to correlate more closely with the back edge of prominent terraces than the mapped fault locations supports the erosional hypothesis.

Abrupt changes in stream gradient or elevation may in some instances relate to faults, but other factors, such as lithology or changing sea level, may also be responsible for nickpoints in the streams (Larson, undated).

Seismicity

Regional seismicity is shown on Figure 5a. With the exception of the seismicity in Santa Monica Bay (see next paragraph), most of the epicenters appear to be bounded on the south by the Anacapa fault. The Malibu Coast fault zone lies within this map pattern and does not have any apparent effect on the distribution of seismicity. Campbell (1990) suggests that most of the local seismicity, including the 1973 Point Mugu earthquake, has been along the Anacapa fault. There was as much as 30mm of uplift during the Point Mugu event. Stierman and Ellsworth (1976) note that the hypocenters for 141 aftershocks from the Point Mugu earthquake did not define a single fault plane associated with the main shock, however the focal mechanisms, in general, project about 10km below the Malibu Coast fault and probably correlate to the offshore projection of the Santa Monica fault (the Anacapa fault). Similarly, a cross-section from Bryant and Jones (1992) shows most of the earthquake activity in the Malibu area from 1981-1988 to be below or south of the Malibu Coast fault and perhaps clustering on the Anacapa fault (Figure 5b). Based on the historic seismic record we conclude that the Anacapa fault is a more active structure than the Malibu Coast fault.

The dense double cluster of events southeast of Point Dume within Santa Monica Bay are the epicenters and aftershocks from two M5.0 earthquakes in 1979 and 1989. These two thrust events are associated with the Torrance-Wilmington fold and thrust belt (Hauksson, 1990). Hauksson and Saldivar (1989) discussed earthquake activity in Santa Monica Bay during the interval 1973-1986 and found that "most of the seismic activity appears to be located to the south of the reverse faults" [Malibu Coast and Anacapa faults].

METHODOLOGY OF INVESTIGATION

The intent of a Fault Evaluation Report is to identify active faults which have surface rupture potential and which can be avoided during future construction activity. To this end two principal criteria have been established to determine which faults should be included in an Earthquake Fault Zone (Hart, 1994).

1. A fault must be "sufficiently active". "A fault is deemed sufficiently active if there is evidence of Holocene surface displacement along one or more of its segments or branches. Holocene surface displacement may be directly observable or inferred; it need not be present everywhere along a fault to qualify that fault for zoning."
2. A fault must be "well-defined". "A fault is considered well-defined if its trace is clearly detectable by a trained geologist as a physical feature at or just below the ground surface. The fault may be identified by direct observation or by indirect methods. The critical consideration is that the fault, or some part of it, can be located in the field with sufficient precision and confidence to indicate that the required site-specific investigations would meet with some success."

In order to evaluate whether or not a fault meets these criteria all available data, both published and unpublished, is considered. This data set includes formally published maps and reports, theses, field trip guides, consultants' reports, and personal contact with geologists who have worked in the area. Data from these sources is assessed and compared with original work based on field observations and interpretation of aerial photographs. The recommendations in the Fault Evaluation Report are translated into a map of active fault traces and recommended Earthquake Fault Zones which are released in Preliminary form for a 90-day review and comment period. Any comments received are considered prior to release of an Official Earthquake Fault Zone map, 180 days after the release of the Preliminary map. These maps may still be modified in the future if significant new information comes to light.

A field reconnaissance of the Malibu Coast fault zone was made over several days in August 1991 and March and April of 1992 to try to verify mapped exposures of the fault and to look for subtle geomorphic expression. However, the degree of development combined with existing natural and landscape vegetation make observation of fault features very difficult. Roadcut exposures, both in the fault zone and elsewhere, commonly reveal highly sheared bedrock. A few field observations have been included in the discussion of individual sites in Table I beginning on page 27, but in general field reconnaissance, without taking time to excavate exposures or contacts, was not very useful to this evaluation.

There are several limitations, in this coastal region, to the interpretation of geomorphic data with respect to slip-rate and recency of displacement: **1)** The general steepness and instability of the Malibu coast, due in part to coastal erosion and regional uplift, has tended to create a very young landscape which does not preserve even early to mid-Holocene geomorphic features in many areas; soils on most slopes are thin and also quite young, hindering their usefulness in trenching studies. **2)** The marine terraces are not very well mapped and just as poorly dated or correlated; it is possible that terraces on either side of a fault, mapped as different by Birkeland (1972), are the same terrace displaced by young faulting; better correlation and control of terraces and their ages would help us to better understand the timing and magnitude of late-Quaternary uplift and faulting. **3)** Without careful, detailed work geomorphic features such as landslide scarps, fault scarps and seacliffs are nearly indistinguishable. **4)** Along the Malibu coast sea-level fluctuations have overwhelmed any tectonic base-level changes so that stream-related indications of vertical tectonics, such as effects on stream profiles, stream incision, and fans issuing from abrupt mountain fronts, cannot be interpreted without ambiguity.

Aerial photo interpretation was attempted at three resolutions: 1:1 viewing of 1:140,000 scale U-2 photos and of standard 1:24,000 scale photos (USGS: 1947 & 1970) to identify gross features, and up to 4X magnification of 1:18,000 to 1:24,000 scale photos (Fairchild, 1928 and USDA, 1952-54) to identify finer fault geomorphology. The specific photos used are listed on page 35. Gross features have been discussed under geomorphology beginning on page 8. Numerous fine features were observed in the aerial photos, including tonal lineaments, abrupt topographic breaks, linear drainages and small drainage deflections. Some of these features coincide with mapped faults, but in most instances they do not. The most likely explanation for the majority of the features is differential erosion along lithologic contacts, old faults, and fractures. Significant aerial photo observations are listed in Table II (p.33).

DISCUSSION OF FAULTS

The following discussion of individual faults begins in the north with the main trace of the Malibu Coast fault zone and proceeds, in sequence, south to the Point Dume fault (Figures 2a & 2b). Two localities, not associated with known faults are discussed last. Faults and numbered localities are shown in greater detail on Figures 3a-d.

• **Malibu Coast fault (main trace)**

Yerkes and Wentworth (1964) described the main fault as a somewhat sinuous north-dipping fault (30° to 80°) with a zone of "intensely sheared and brecciated rock" up to 75 feet wide (at Malibu Canyon) and several subsidiary faults. The main trace of the Malibu Coast fault has been mapped from Sequit Point (on the Triunfo Pass quadrangle, Figure 3a) eastward to Carbon Beach (on the Malibu Beach quadrangle, Figure 3c).

The main (northern) trace of the Malibu Coast fault is probably also the oldest trace, based on the apparent tens of kilometers of strike-slip displacement (Campbell & Yerkes, 1976; Wright, 1991). There is no known evidence of Holocene displacement on the main trace of the Malibu Coast fault. The youngest identified fault displacement along the main trace of the Malibu Coast fault zone is pre-75,000 years old (locality 36). Late-Quaternary displacements on or near the main trace have also been observed at localities 5, 8, 18, 35 and 41, and possibly at 7 (see Figures 3b and 3c and Table I). There were either no Holocene deposits exposed at these additional sites or young Holocene deposits (colluvium and soils) were not displaced. Displacements at locality 7 are probably landslide related. Deflected drainages which may also document late-Quaternary displacement have been discussed on page 8. The following paragraphs describe segments of the main trace in greater detail.

west from Trancas Canyon - The fault is mapped here mostly as a single trace and is expressed geomorphically by several saddles and deflected drainages east of Los Alisos Canyon (Figures 3a, 3b & 4b). A possible back-facing scarp at Sequit Point and offshore (features A & B, Table II) is a probable fault-line feature developed along resistant upper Topanga Formation sandstone. The saddles, too, are probably fault-line features, whereas some of the small deflected drainages are more likely tectonic, as indicated by faulted terrace deposits exposed in trenches. Geomorphic expression, however, appears to be restricted to the higher older (pre-124,000 year old) terrain. San Nicholas Canyon, which is entrenched through the 124,000 year old terrace, shows no tectonic effects. Although moderately well defined between Trancas Canyon and Los Alisos Canyon, to the west this fault segment is concealed and poorly located. There is no evidence for Holocene activity. The westward offshore extent of the Malibu Coast fault is unknown, although Junger and Wagner (1977) noted a possible extension of faulting east of Hueneme (submarine) Canyon where, within a zone of apparent faults, the top of the Miocene rocks are displaced vertically 200 m, north side up (area is just west of Figure 2a).

Trancas Canyon to Ramirez Canyon (trace of Campbell et al, 1970) - The main (northern) strand of the fault zone, as mapped by Campbell and others (1970) and Yerkes and Campbell (1980), is an interpreted structure separating Modelo Formation, rocks of the Topanga Group (including Conejo Volcanics) and older Paleocene and Cretaceous rocks on the north from Monterey Shale, Trancas Formation and Zuma Volcanics on the south. Yerkes and Campbell (1980) differentiate Modelo Formation from Monterey Shale based on provenance of the sediments. They found that the sands of the Modelo Formation north of the fault were derived from northern and eastern sources, whereas the sandy units of the Monterey Shale and other Tertiary rocks, south of the fault, were derived from southern sources. Dibblee (personal communication, 1991) considers the lower part of the Modelo Formation and the Monterey Shale in the Malibu area to be the same unit, calling both the Monterey Formation. Similarly he considers the Conejo Volcanics (part of the Topanga Group) and Zuma Volcanics to be a single unit, which he calls the Conejo Volcanics. He considers the northern trace of the Malibu Coast fault of Campbell and others (1970) to be a depositional, partly unconformable contact. This fault segment shows no geomorphic expression and has not been seen directly in exposures. It is only poorly to moderately defined and (except just west of Trancas Canyon; locations 7 & 8) has little or no evidence of even Quaternary activity. Shears within soil reported at locality 7 may be landslide related: the soil at this locality is displaced along a south-dipping normal shear, whereas the mapped fault in this vicinity is a shallowly north-dipping thrust fault. This locality also is adjacent to a mapped landslide and the shearing was believed to be landslide related by others who saw the exposure (Jeffrey Johnson, personal communication, 1992).

Trancas Canyon to Ramirez Canyon (trace of Dibblee & Ehrenspeck, 1990-92) - Dibblee maps the main trace 1/4 to 3/4 mile south of Campbell and others (1970), in part separating Conejo volcanics and Monterey Shale from Topanga Formation. This location coincides with a notable break in slope (which may be largely a result of different bedrock resistance) and is partly supported west of Zuma Canyon by site specific observation (locality 10). Late-Quaternary faulting at locality 17 may also be related. Earlier mapping by the U.S.G.S. also showed a fault in this location (Schoellhamer and others, 1962) but this trace was deleted from the later mapping because they felt that there was no compelling evidence for it (Yerkes and Wentworth, 1965; Campbell and others, 1970; Russ Campbell, oral communication, 1992). In general this fault is poorly defined and has no evidence of Holocene displacement.

Ramirez Canyon to Solstice Canyon (trace of Campbell et al, 1970) - This fault segment was mapped by Yerkes and Wentworth (1965) and Campbell and others (1971), separating Monterey Shale on the south from rocks of the Topanga Group on the north. Dibblee (personal communication, 1992) considers the contact to be depositional. The map pattern suggests a near-vertical contact. If it is a fault it has no geomorphic expression other than a few minor saddles along the ridgelines. The obvious deflection of Solstice Canyon can be explained as an artifact of lithology and ancient coastal processes (as described on p.8) or as an offset along the main fault trace of Dibblee & Ehrenspeck (1990-92) which joins the Solstice fault at Latigo Canyon to the west (Figures 3b&c). Direct evidence of faulting was not exposed in the one investigation known (loc.24a).

Solstice Canyon to Malibu Creek - This fault segment separates rocks of the Topanga Group and Conejo Volcanics on the north from Monterey Shale and Trancas Formation on the south (Yerkes and others, 1970; Yerkes and Campbell, 1980). In one investigation (loc.27a) the fault was found to dip north at 55° with a shear zone at least 175' wide. The fault is, in general, poorly known and has, with one exception, virtually no geomorphic expression. The only place where this fault was visible in aerial photographs was within a bedrock high at the Pepperdine campus (loc. 35, loc. K), but it was not visible to the east where bedrock was covered by Quaternary terrace deposits or younger stream deposits. The fault, as mapped by Yerkes and Campbell (1980) separates Conejo volcanics from Monterey shale. This locality was confirmed during grading for the sewage treatment ponds (see Figure 3d). At locality 36 the main trace did not affect younger terrace deposits estimated to be 75,000 years old. No clear evidence of Holocene displacement has been found. The possibly related Tennis Court fault is a north-dipping thrust which displaces late-Quaternary terrace deposits.

Malibu Creek to Carbon Beach - Two fault locations have been inferred across the Malibu Creek floodplain. Investigations in the floodplain have so far not uncovered any evidence of precise fault location or Holocene activity (W. LaChapelle, oral communication, 1992; E. Gath, oral communication, 1992). East of Malibu Creek the main trace has been observed to thrust basalt over Quaternary terrace deposits. A possibly related fault immediately to the south (loc.42) is not along any previously mapped trace but may be related to faults observed at localities 39 and 43. Although affecting late-Quaternary terrace deposits and possible pre-Holocene stream deposits there is no clear evidence of Holocene activity along this poorly defined splay or the main trace to the north. Eastward from Carbon Beach the fault runs offshore and then may come ashore again as the Potrero Canyon fault or some other strand of the Santa Monica fault zone (Jennings and Strand, 1969; McGill, 1980). This possible eastward extension should be evaluated in the future, after current studies by CalTech geologists are concluded.

Southern trace - Corral Canyon to Marie Canyon (main trace of Dibblee & Ehrenspeck, 1990-92) - This fault segment separates Monterey Shale on the south from Trancas Formation (Yerkes and Campbell, 1970) or Topanga Formation (Dibblee and Ehrenspeck, 1990-92). Other than one saddle this fault has no geomorphic expression and has no evidence of Holocene displacement.

• Malibu Bowl fault (part from Marie Canyon to Malibu Creek)

This short portion of the Malibu Bowl fault has been isolated, by warping and erosion, from the main thrust fault. It is mapped as a south-dipping fault truncated by the Malibu Coast fault (Yerkes and Campbell, 1980). It separates a block of Conejo Volcanics on the south from Sespe Formation on the north. This fault segment may have been reactivated in Quaternary time by movement on the Malibu Coast fault (localities 35 & 38; see also Figure 3d). The fault is poorly identified and located in this area and has no clear evidence of Holocene displacement.

• Solstice fault

The Solstice fault corresponds to the western half of the Puerco Canyon fault, as mapped by the U.S.G.S. (Campbell and others, 1970; Yerkes and Campbell, 1980). It branches off from the main trace at Ramirez Canyon and extends eastward to the mouth of Solstice Canyon (Figures 3b and 3c). This fault was called the Solstice fault by Cleveland and Troxel (1965), and this name will be retained here. The fault is very steep, based on the mapped trace, and even dips to the south between Latigo Canyon and Solstice Canyon. Dibblee (personal communication, 1991 & 1992) considers much of this segment to be part of the main trace of the Malibu Coast fault. Stratigraphic differences across this fault are not as great as across the main trace, but the fault principally separates Monterey Shale on the north from Zuma Volcanics and Trancas Formation on the south (Campbell and others, 1970; Yerkes and Campbell, 1980). This fault does not appear to be the same as the Puerco Canyon fault, mapped between localities 27 and 37, because of the notable difference in fault dip and a lack of demonstrable continuity between Corral Canyon and Solstice Canyon.

One of the youngest displacements observed within the Malibu Coast fault zone (latest Pleistocene and probable Holocene) is along the Solstice fault, west of Solstice Canyon. A recent study between Latigo and Solstice Canyons (locality 26) by RSA Associates, Inc. (1990) found evidence of possible Holocene displacement along the Solstice fault. The fault occupies a prominent sidehill bench and juxtaposes Trancas Formation and Zuma Volcanics on the south against Modelo Formation on the north. RSA Associates, Inc. (1990) found a 20-foot-thick section of colluvium downdropped along the fault with numerous paleosols identified within the colluvial section. The fault, expressed as a prominent one-foot-thick gouge zone, marks the northern margin of the colluvial section and extends up to the modern (disturbed) surface. Appendix A to the consultant's report, by Roy J. Shlemon, includes the conclusions that the upper 5 feet of faulted colluvium is probably Holocene (based on a ^{14}C date of 17,800 at a depth of 8 feet) and that there may have been at least two displacement events during Holocene time. Although the fault zone is "supposed to be" a north-dipping structure, the fault was found to dip south in the consultant's trenches, roadcut exposure, and canyon exposures to the east. The fault pattern, as well, seems to support a southerly dip to this fault segment, at least at elevations above sea level. The consultant assumes that the fault dips back north at depth. The difference in structure, age and an over 2000 foot left-step between defined segments of the fault suggest, however, that this is not the same as the Puerco Canyon fault which is mapped to the east.

It is possible that the feature at locality 26 may be a south-dipping normal fault above, and secondary to, an active north-dipping thrust fault that may daylight further south, offshore. The strong surface expression (sidehill bench at locs. H & I) and the exposed (in trenches) section of faulted colluvium very strongly suggest Holocene displacement, although it is possible that the surface expression is solely a result of, or has been enhanced by, strong shaking. An eastward-pointing V-shaped graben appears to have formed on the ridgetop here, in addition to the obvious sidehill bench. These features are reminiscent of ridgetop-spreading phenomena observed in the Santa Cruz Mountains following the 1989 Loma Prieta earthquake (see, for example, Hart and others, 1990). Possibly supporting an interpretation of localized shaking effects is the limited extent of the otherwise remarkably prominent sidehill bench. Topographic expression is limited to the flank of this one east-west oriented ridge and does not continue either east across Solstice Canyon or across the western end of the ridge. If the sidehill bench were solely a result of tectonic fault displacement such a strong feature would be expected to have a greater extent. The well-developed shear zone, however, indicates that faulting has certainly been a part of the process.

To the west of locality 26 the Solstice fault is inferred to run along the bottom of Escondido Canyon. Although at least one interpretation would give the fault there a distinct north dip, it is difficult to precisely map the fault. It's location is based on the separation of rock units which are known, in some areas, to intertongue (Yerkes and Campbell, 1979). West of Escondido Canyon the fault is not well defined and could not be located in site-specific investigations (locality 21).

• **Puerco Canyon fault**

The Puerco Canyon fault, as originally mapped by the U.S.G.S. (Yerkes and Wentworth, 1965; Yerkes and others, 1971; Yerkes and Campbell, 1980) extended from Ramirez Canyon, on the west, to Malibu Beach, on the east. The name is restricted here to the fault as mapped from Corral Canyon to Malibu Beach, the portion to the west being called the Solstice fault (see discussion above). The originally mapped fault is concealed between Solstice Canyon and Corral Canyon. The Puerco Canyon fault has stepped left from the Solstice fault about 2,000 feet and dips to the north, as exposed in Corral Canyon and several additional canyon exposures further to the east. The detailed studies for the proposed Corral Canyon Nuclear Power Plant (Yerkes and Wentworth, 1965) left some doubt about the continuity of the fault as mapped between Corral Canyon and Puerco Canyon and suggested that some of the observed shears could be landslide related.

Late-Quaternary terrace deposits are displaced at localities 28, 29 and 30. At Corral Canyon the Puerco Canyon fault was found to not displace 8,000 to 10,000 year old deposits (Yerkes and Wentworth, 1965, p.170-171). No evidence for Holocene displacement has been found along the Puerco Canyon fault. A break in slope (locality L, Table II) is roughly coincident with the fault location but is indistinguishable, without further study, from a landslide scarp or ancient seacliff. Probable Holocene displacement has occurred near the eastern portion of the Puerco Canyon fault (near Puerco Canyon, locality 37, see Table I) and this site is discussed in more detail below (page 19, 31).

• **Latigo fault**

The Latigo fault (named by Dibblee, personal communication, 1992) branches south from the Solstice fault at Escondido Canyon and separates Zuma volcanics on the north from Trancas Formation on the south. This contact, which is concealed by colluvium, coincides with a somewhat abrupt mountain front. Very little else is known about this fault. A recent trench study for development (locality 25b) suggests that the soil may be displaced across this fault, although the interpretation is questionable as the fault was not directly observed and no shears were found in the soil.

The Latigo fault has moderate topographic expression which may be tectonic, or which may be a response to resistant volcanic rock at the back edge of a coastal terrace, or it may be a combination of these factors. Aerial photo examination of this fault shows no apparent effects on streams which cross it. If young displacement has occurred, as possibly suggested at locality 25b, it may only be a minor response, along with the Solstice fault, to strong ground shaking due to earthquakes on the offshore fault system.

• **Escondido Thrust**

A nearly flat to north-dipping, south-verging thrust fault (Figure 3b), called the Escondido thrust by Campbell and others (1966), extends from Trancas Canyon eastward to Escondido Beach. It generally separates Monterey Shale (below) from Trancas Formation and Zuma Volcanics above, although to the west of Zuma Canyon, Trancas Formation also crops out below the thrust (Campbell and others, 1970). Dibblee (personal communication, 1992) calls the eastern portion of this fault, from Walnut Canyon eastward to the coast, the Ramirez fault. The youngest documented displacements involve marine terrace deposits (124,000 ybp and older), although as mapped by Campbell and others (1970) and Dibblee & Ehrenspeck (1990-1992) the fault is concealed in several localities by Quaternary deposits. Observed exceptions are discussed below.

The westernmost segment of this fault, which coincides in part with the main trace of Dibblee and Ehrenspeck (1990-92), is very flat-lying, placing volcanic rocks over Quaternary terrace deposits (localities 9 & 9a). No Holocene deposits other than young unfaulted soils were observed at the fault exposures. Faults at locality 20 also affect Quaternary deposits, but they do not coincide with the fault trace as mapped. Other observations of Quaternary faulting (localities 11, 12, 13, 16b & 25a) are notable in that they are of steeply dipping or south dipping faults; these observations do not match the general interpretation of a gently north-dipping thrust fault but may instead indicate more recent deformation of the thrust sheet, suggesting that the Escondido thrust may be inactive and deformed by later folding.

• **Paradise Cove fault**

An east-west trending fault, (called the Paradise Cove fault by Dibblee, personal communication, 1992) separates a tightly folded dolomitic unit from more normal Monterey Shale to the south (Campbell and others, 1970). It is mapped west from Paradise Cove and appears to be overridden by the Escondido Thrust (Campbell and others, 1970)(see Figure 3b). The fault, itself, is not exposed but is mapped based on the lithologic contrast. Dibblee (personal communication, 1991 & 1992) suggests that this may be the actual continuation of the western portion of the Escondido thrust rather than the sinuous trace to the north (Dibblee's Ramirez fault). Ziony and others (1974), show the fault as not displacing late Quaternary deposits (Figure 2a) and it is mapped by Campbell and others (1970) and Dibblee (personal communication, 1991 & 1992) as being concealed by Quaternary terrace deposits (Figure 3b). Study of aerial photos shows no evidence of faulting or deformation of the terrace surface developed above the 124,000 year old marine terrace platform which crosses this fault. This fault may be related to the Holocene fault shown offshore by Greene and Kennedy (1986), however there is no geomorphic or stratigraphic evidence along the onshore fault for late Pleistocene or Holocene displacement. We consider a connection between the Paradise Cove fault and active offshore faulting to be speculative. See also the discussion of offshore faults on page 20.

• Point Dume fault

The southernmost onshore fault in this zone is the Point Dume fault (Figure 3b), which separates Monterey Shale on the north from Zuma volcanics and Trancas Formation on the south. This fault apparently does not displace late Pleistocene terrace deposits since marine terrace deposits are at roughly the same elevation on both sides of the fault. Vertical striae are visible on slickensided bedrock surfaces in the bluffs (loc.14). There is no indication of Holocene displacement. Surface expression (scarp?, loc.F) is probably due to the greater resistance of the Trancas Formation and volcanic rocks south of the fault.

• Other Critical Sites

• Locality 33 Faulting at this locality, near Puerco Canyon, is known from several trench exposures and a boring (see Table I). Faulting clearly affects late Quaternary marine terrace deposits and may affect soil thickness. The observed faults, however, are poorly correlated with each other, are not part of any mapped fault, and in fact, are not known beyond the limited man-made exposures. Although possibly active, the faults are not clearly so and are poorly defined.

• Locality 37 At Winter Mesa three north-dipping faults have been mapped, between the Puerco Canyon fault and the Malibu Coast fault. Only the central of the three faults exposed appears to displace Holocene deposits (and normal displacement at that), although data on the northern fault do not preclude Holocene displacement. Within the bedrock the faults are parallel to bedding. Except for possibly two places, none of the three faults had any surface expression nor did they coincide with any features on aerial photos. The only features noted were 1) a short linear drainage along part of the northern trace (but the drainage is not clearly fault-related and the fault could not be found in a trench across its projection to the northwest) and 2) a vague, north-facing scarp or vegetation boundary near the middle fault (due to the scale and clarity of the 1928 photos used this feature may be imprecisely located or misinterpreted).

Based on five trench exposures, the central fault may have a length in excess of 500 feet. It apparently does not continue eastward, however, as it could not be located in a trench 180 feet east of the easternmost exposure. The central fault may also be much shorter than interpreted, since the sense of separation changes from normal to reverse between exposures which are 140' apart. The reversal of separation may be due to lateral displacement, however, the inferred connection also requires a 40' left bend of the fault. These uncertainties suggest that the fault exposures at this site may be discontinuous bedding-plane faults. Furthermore, the faults exposed in the various trenches are within a deformed unit of the Monterey shale which was observed by Yerkes and Wentworth (1965) and Yerkes and others (1971) to be severely sheared and folded with numerous small faults. Both the consultants and DMG staff who visited the site felt that these are secondary effects. Site data that indicate only one minor displacement on the middle fault in the past 124,000 years support this impression. The on-site faulting is probably related to continued compression of the deformed Monterey Shale unit or perhaps is related to an active fault to the south. This could be the Puerco Canyon fault (which may be expressed by a slope break and possible degraded scarp along the south side of the mesa), or the Holocene fault of Greene and Kennedy (1986) about 1 mile to the south, or the Santa Monica fault further offshore.

In summary, the faulting at locality 37 is defined only within the extent of trenching and was considered to be secondary to some as yet undefined fault, probably to the south. Although the central fault at this locality is believed to be Holocene-active its continuity across the site is not certain and it was found to die out relatively abruptly to the east. The faults at this locality are not well-defined and should not be projected very far beyond their limited trench exposures.

• **Offshore Faulting**

Various interpretations of the offshore fault pattern near Malibu have been presented by other workers. The most thorough have been by Greene and others (1975) and Junger and Wagner (1977). Other maps of offshore faulting have been largely compilation of the work of others (Ziony and others, 1974; Jennings, 1975; Yerkes and Lee, 1979; Greene and Kennedy, 1986; and Ziony and Jones, 1989). The interpretation presented by Greene and others (1975) for the Malibu coast came from ongoing work by Arne Junger and made a queried projection of an offshore fault to connect with a mapped onshore fault. The offshore interpretation was based on sparker and Uniboom data from the *R/V Kelez*. Subsequent interpretation by Junger (Junger and Wagner, 1977) showed the offshore fault veering southwestward, offshore from Point Dume. This later map utilized all of the *R/V Kelez* data as well as also considering some earlier data collected by the *R/V Polaris* (H.Wagner, personal communication, 1992). The compilation by Greene and Kennedy (1986) utilized the earlier work by Greene and others (1975) as the principal source for the Malibu area and also showed a connection of "Holocene" offshore faults with an onshore fault in the vicinity of Paradise Cove.

A review for this report, by Division geologists and marine geologists, of the tracklines and data used (see Figure 6) found that the offshore data was ambiguous for both Holocene displacement and for the inferred continuity and projection of the offshore faulting. Michael Kennedy and Gary Greene (personal communication, 1992) acknowledged that the use of the term "Holocene" on their recent map (Greene and Kennedy, 1986) was perhaps inappropriate in that the faulted offshore sediments have not been dated and could be older than Holocene. The "Holocene" designation for the offshore fault was based on the apparent displacement of the base of "young" acoustically transparent sediments within 5 to 15 meters of the sea floor, as detected in offshore seismic-reflection profiles (Greene and others, 1975). Although these sediments appear to be disrupted in several trackline crossings, it was not apparent from the data at hand that these were, in most cases, necessarily due to faulting. Review of the trackline data also shows that some of the inferred offshore faults are not visible on several tracklines, which calls into question the inferred connections and continuity. Possible faults or discontinuities were also observed where faults have not been shown on published maps. The published offshore fault interpretations are based on only a few trackline crossings and are judged to be uncertain and largely non-reproducible.

Some of the mismatch of data with interpretations may involve navigational error. It is generally acknowledged that the navigational accuracy of the research vessels in the early 1970's was not up to todays standards and the tracklines of the *R/V Kelez*, which are believed to have been as much as ½-mile off in the Santa Barbara channel (Peter Fisher, personal communication), may have also been mislocated in the Malibu area.

In summary, there appear to be two major uncertainties with regard to the offshore data:

1. the data do not clearly demonstrate Holocene fault rupture
2. the data are not adequate to demonstrate the connection between any two fault crossings or to establish a definite fault pattern

A connection to onshore faults is therefore uncertain as is any inference of Holocene activity for such onshore faults.

GENERAL DISCUSSION

Most of the faults of the Malibu Coast fault zone are mapped principally on their separation of, and truncation of, rock units. Actual exposures of these faults are not common or continuous as the faults are commonly obscured by thick soils, colluvium, terrace deposits and landslide debris. Moreover, the continuity of individual traces is not well-expressed geomorphically, not even in well-preserved terrace surfaces.

Data on the faults in this zone have come from numerous site-specific investigations. Many of these studies (mentioned in detail in Table I) have found faults where they had not been previously mapped, indicating that the pattern and distribution of faulting is probably much more complex than shown on Figures 3a-c. At a few localities, faults may involve undated but possibly Holocene materials.

The Malibu Coast fault zone is apparently a less-active part of the tectonic boundary between the Transverse Ranges and the Peninsular Ranges, the more active part being the offshore Anacapa and Santa Monica faults. This interpretation is based on the distribution of seismicity, the apparent paucity of Holocene displacement onshore, and the continuity of the offshore faults as a province-bounding fault system. Greater activity along the faults to the south is in accord with observations of Bull (1987) along the south front of the San Gabriel Mountains where he noted that, with time, the locus of more active faulting appeared to shift outward from the mountain front.

The main trace of the Malibu Coast fault zone, which is also the oldest trace, has an outcrop pattern which suggests a steeply dipping or near-vertical fault along much of its length. Late-Tertiary left-lateral displacement of "several tens of miles" (Campbell, 1990) along the main trace of the Malibu Coast fault has juxtaposed different basement rocks: Jurassic meta-sediments and Cretaceous plutonic rocks on the north against Catalina Schist on the south. Upper Cretaceous and lower Tertiary rocks on the north are absent on the south. Miocene rocks north and south of the Malibu Coast fault show different provenance.

Although the fault zone had dominantly strike-slip displacement during the late Tertiary, the Quaternary faulting has accommodated transpressive stresses, with reverse, thrust and left-oblique displacements. Faults which show late Quaternary displacement include some which are shallowly north-dipping and several localities which are not along well-identified fault traces. These late-Quaternary displacements appear to document the introduction of compressive stresses expressed in a broader, and perhaps more random, fault pattern between the main trace and the offshore faults. The faults which have had Holocene displacement suggest scattered discontinuous rupture which still includes elements of both strike-slip and compressive motion. If this interpretation is correct, then future surface rupture should also be expected to occur in a more or less random pattern as the broad zone of pre-existing planes of weakness adjusts to left-oblique stress and strong ground shaking. Strain partitioning might be expected with lateral slip concentrated along the steeper shear zones and thrusting along the shallower faults.

Although extensively mapped, the fault traces are not well expressed geomorphically. Gross geomorphic features, such as deflected major drainages and the relatively abrupt mountain front, do not support Holocene fault activity. Some streams follow the main fault trace of Dibblee and Ehrenspeck (1990-92); however, these may be fault-line features. Although it has been suggested (Yerkes and Wentworth, 1965) that the larger left-laterally deflected drainages may be merely a result of bedrock resistance and old shoreline processes rather than of tectonic displacement (see discussion on p.9) there probably has been some strike-slip influence in the past. Significantly, however, several major drainages appear unaffected. Likewise, smaller drainage deflections noted by Dibblee (1982) are intriguing but inconclusive. Even if some of the stream deflections are tectonic, they occur in older (pre-124,000 year old) terrace surfaces and do not indicate Holocene activity. There are no stream deflections within the 124,000 year old terrace. It is quite likely that lateral displacement did occur in the Quaternary but has diminished into the Holocene. The abrupt mountain front also was considered (by Yerkes and Wentworth, 1965) to be an erosional rather than tectonic effect and it certainly appears to be principally erosional in its present form. There is no clear geomorphic expression of the main fault or other traces to the south, where they pass beneath, and locally into, the lower portions of late Quaternary marine terraces.

Some of the fault traces also are not well defined in terms of bedrock mapping. There is a significant difference of opinion over the location of the main fault trace. The main trace mapped by the U.S.G.S. (Campbell and others, 1970) from Trancas Canyon to Solstice Canyon (Figure 3b) is probably a real fault, based on the lithologic and structural contrasts recognized by the Survey geologists, although it is not recognized as a fault by Dibblee (personal communication, 1991 & 1992). Dibblee's main trace between Trancas and Ramirez Canyons may be an extension of the Solstice fault since he maps it as a continuous fault and it seems to have a similarly steep dip. Although mapped also by Schoellhamer and others (1962), this fault, west of Ramirez Canyon, was deleted from later maps by the U.S.G.S. (Yerkes and Wentworth, 1965; Campbell and others, 1970) and evidence for it is sparse. There is less dispute over the other significant fault traces, such as the Solstice, Latigo, and Puerco Canyon faults, although surficial deposits often obscure the precise fault location and, in the case of the Solstice and Puerco Canyon faults, two unrelated faults may have been connected. Numerous additional local faults, many offsetting late-Quaternary terrace deposits, have been observed in excavations for individual site investigations, but have not been correlated to any previously mapped faults. These local faults are probably indicative of wide-spread discontinuous faulting throughout a broad zone south of the main fault trace.

With respect to recency of displacement, there are numerous localities along the Malibu Coast fault zone where late Pleistocene terrace deposits are faulted, however, there are relatively few localities that show evidence of Holocene displacement. These localities are detailed on Figures 3a-c and Table I (page 27). Probable Holocene displacement has been reported only at Winter Mesa (locality 37) and between Latigo and Solstice Canyons (locality 26). Possible Holocene faulting has been reported in a few localities based on irregular soil thickness (localities 6, 9a, 22, 25b, 33, 35, 35a and 38). Two of these localities (6 & 33) are not along previously mapped faults and are poorly defined; two are on the Escondido thrust (9a & 22) which is also poorly defined; and two (localities 35 & 38) are on the main trace but are poorly documented or ambiguous. Youthful geomorphic expression exists only at the Latigo Canyon locality (loc.26). Stream displacements are not always consistent and, due to the age and activity of the coastline, are not well dated. The data suggest, however, that consistent lateral displacement along well-defined faults has essentially ceased.

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<u>OVERVIEW OF CONCLUSIONS</u>

Although thrust displacements clearly occurred into the late Pleistocene, as indicated by the faulting of post-124,000 year old terrace deposits, Holocene activity has principally been demonstrated only in a limited fashion on steeply-dipping structures which appear to be not directly related to the older major north-dipping thrust faults. Displacement on the main fault trace appears to have ceased to any significant extent over 75,000 years ago, and subsequent faulting appears to have been scattered and discontinuous. The faulting at Winter Mesa (locality 37), as well as late-Pleistocene faulting at many other sites, appears subparallel to, and may be controlled by, bedding and lithologic contacts. These observations, coupled with the distribution of epicenters shown on Figure 5, support Campbell's (1990) interpretation that the most recent displacements along the Malibu Coast fault zone "might have formed as a surficial response to seismogenic displacement at depth, possibly on the Anacapa fault, rather than being produced as intrinsic parts of seismogenic displacement on the Malibu Coast fault."

I recommend that those portions of the fault zone shown on Figure 7, and **as described below**, be included in an Alquist-Priolo Earthquake Fault Zone. Conclusions and recommendations are also summarized in Table III.

The Solstice fault, from Escondido Canyon on the Point Dume quadrangle to Solstice Canyon on the Malibu Beach quadrangle should be included in an Earthquake Fault Zone. This portion of the fault is considered to be well defined as it has been mapped in essentially the same location by most parties who have worked in the area (Campbell and others, 1970; Yerkes and Campbell, 1980; Dibblee and Ehrenspeck, 1990-92) and has been confirmed in several trenches (RSA Associates, 1990). It is considered to be sufficiently active based on a reasonable inference of Holocene displacement according to trench data (RSA Associates, 1990). Also contributing to both the definition and the inferred recency is the well-developed sidehill bench along the fault between Latigo Canyon and Dry Canyon. **The V-shaped ridgetop graben** may or may not be a result of primary faulting, but **should be considered for its coseismic ground rupture potential**, regardless. The western portion of the Solstice fault, from Escondido Canyon to Ramirez Canyon, is not well defined since it has not been located in trench investigations specifically looking for it.

The Puerco Canyon fault is not well defined. Near its western end, east of Corral Canyon, the fault is overlain by sediments representing most of the Holocene. At Winter Mesa (locality 37) evidence is suggestive of Holocene displacement on one or more minor short faults <u>north</u> of the Puerco Canyon fault, but the continuity of these faults and their relation to the Puerco Canyon fault are uncertain. **A very limited zone should be established around the exposures of the northern and central faults at locality 37.**

It is possible, and perhaps likely, that the locations described above merely represent ground shaking effects localized along pre-existing planes of weakness, and that the evidence for displacement may not be representative of the whole fault trace as shown. They are, however, sites of probable Holocene ground rupture at which shaking effects are, for now, indistinguishable from tectonic displacement.

The main trace of the Malibu Coast fault (the northernmost trace shown on Figures 3a,b, and c) is largely concealed with no evidence of Holocene displacement. It has been documented as pre-Holocene west of Malibu Creek. Although moderately well defined by lithologic contrasts, it is not sufficiently active and should not be zoned at this time. One or two short segments of the Malibu Bowl fault, west of Malibu Creek, may have become involved with the main trace of the Malibu Coast fault and are probably the same age and should not be zoned. The main trace of Dibblee and Ehrenspeck (1990-92; shown on Figures 3b and 3c) is not well defined and has no indications of Holocene activity.

The Latigo fault, the Escondido thrust, the Paradise Cove fault, the Point Dume fault, and other unnamed faults south of the main trace, similarly, show no evidence of Holocene displacement and are thus not sufficiently active. The Escondido thrust is also poorly defined over most of its length. Several unconnected fault traces, observed in isolated localities, are not a part of any well-defined faults.

It is probable that there are many more undiscovered localities of late Quaternary and possibly even some Holocene faulting which may be distributed across many of the faults and other fractures within the broader Malibu Coast fault zone. It should not be expected that many of these localities will have demonstrable predictability or continuity with each other.

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TABLE I

DESCRIPTIONS OF INDIVIDUAL LOCALITIES (SEE FIGURES 3 a,b,c,d)

(fault observations from published and unpublished reports)

key to abbreviated sources of observations: CS - Chuck Swift; DG - Dale Glenn; DK - Don Kowalewsky; EG - Eldon Gath: GB - Glenn Borchardt; HR - Hugh Robertson (Robertson, 1981 & 1984); HT - Harley Tucker; JH - Jeff Holt; JJ - Jeff Johnson; JM - John Merrill; JS - Jim Slosson; MM - Mike Mills; RH - Robert Hill; RL - Richard Lung; WLC - William LaChapelle; pc - personal communication; # - refers to locality number described in reference cited.

TRIUNFO PASS QUADRANGLE (Figure 3a)

1. No faulting was observed in a 5-foot deep, 325-foot long trench which penetrated into terrace deposits above the presumed 124,000 year old marine terrace abrasion platform (DK,pc). Previous seismic lines had suggested a bedrock anomaly in the trenched area (CS,pc).

2a,b. A zone of thick terrace or old debris flow deposits was observed (in 5'-deep trenches) where the fault has been mapped, with shallow bedrock to either side; some shears were noted within these deposits as well as within bedrock; deposits are as much as 30' thick (based on borings) (Kowalewsky, 1990, #14).

3. A shear zone (E-W, 25°N) was exposed in trenches, with terrace deposits [Malibu terrace or older] on the north displaced over basalt (apparent normal separation), but no displacement was observed in soil; [data may indicate lateral offset] (California Geo/Systems, 1988).

4. Dibblee and Ehrenspeck (1990) show the Malibu Coast fault at the boundary between Paleocene marine rock and young landslide debris.

POINT DUME QUADRANGLE (Figure 3b)

5. Bedrock (Trancas Formation) thrust over terrace deposits (Qt) exposed in excavation for a retaining wall; fault generally dips 45°-69°N but as shallow as 20°; no obvious soil or colluvium displacement, including stoneline estimated to be less than 2000 years old; faulted Qt estimated to be 125,000 to 200,000 years old (Kovacs-Byer-Robertson, Inc., 1984; Shlemon, 1984), but may be older, based on elevation.

6. Branching fault (N80°W,51NE) displaces terrace deposits [Dume terrace ?]; may affect soil thickness or profile in one trench exposure (1½'thicker to the south) but similar effect not seen in other exposures; main fault trace observed in bedrock in trenches to the north where a young overlying soil was not affected. (Mountain Geology, 1990a).

7. South dipping normal shear exposed in trench and observed in boring (dips 60°S); may be fault or landslide; bedrock and soil displaced; (JJ,pc). [This locality is adjacent to a mapped landslide].

8. Entire package of terrace deposits [pre-Malibu terrace] cut by fault, overlain by colluvium (JS,pc).

9. Volcanics thrust over Qt [Malibu terrace] along flat-lying fault or slide plane exposed in trench; striae on fault/slide plane trend east-west (Kowalewsky, 1990, #13; field observation for this report).

9a. The northern margin of a gently north-dipping fault zone was exposed in trenches. Terrace deposits [Malibu terrace] and basalt were thrust over shale and siltstone; soil thickens across some faults by as much as one foot, but breaks are not abrupt and no obvious shears were observed within soil; believed to be the same fault as at locality 9 (JH,pc; Mountain Geology, 1990c).

10. Reverse faulting reported at two localities: north of road, grading exposed Monterey Formation thrust over Tbv (andesite flow breccia) along northeast dipping fault; south of road, Tbv reportedly thrust over Qt based on boring (Geoplan, Inc., 1988 & JM,pc).

10a. No faults visible in Zuma Canyon stream bank cut into lateral canyon fan deposits; probably 95% exposure (field observation for this report).

11. 5' deep trenches into Qt [Corral or Malibu terrace] across mapped trace did not find fault as mapped but did find minor faults with different trend (N21°E, 76°E & N01°W, 72°E); the first of these faults resulted in 1" vertical separation of a gravel bed, down to the east; the second may have had a little more than 1' separation, also down to the east (DK,pc; Kowalewsky, 1990, #12).

11a. Possible fault separating Monterey shale from upper Topanga Formation inferred in this vicinity by Dibblee (and Ehrenspeck, 1990-92), however mapping by Campbell (oral communication, 1992) at this locality found a clearly depositional contact between Monterey shale and Trancas Formation (equivalent here to Dibblee's upper Topanga Formation).

12. Fault zone 10-20 feet wide does not offset slopewash; bedrock fault (N74°E, 34°SE) places Monterey formation over Trancas Formation; one splay (N40°E, vertical) does offset terrace deposit estimated by consultant to be 124,000-240,000 years old [but probably Malibu terrace] (KBR, 1980a; Robertson Geotechnical, 1985).

13. Shear zone 15' to 25' wide observed in trench; shears dip south 25° to 80°; shears do not cut overlying moderately developed soil; no terrace deposits present (HT,pc).

14. Point Dume fault strikes E-W, dips 60°-65°N; striae on fault plane indicate pure dip-slip (field observation for this report). Yerkes and Wentworth (1965, p.144) state that this fault is unconformably overlain by Dume [124,000 year old] marine terrace deposits.

15. Escondido thrust fault relocated based on separation of Trancas Formation from Monterey Shale as exposed during site investigation (trenches, borings and surface exposures); no age relationships discernible (Leighton and Assoc., 1990).

16a. Two faults mapped, based on lithologic breaks and borings, east of northern road crossing (N64°E, 40°NW & N65°W, 47°NE); no data to assess Holocene activity (DK,pc; Kowalewsky, 1990, #11).

16b. At southern road crossing a high-angle fault offsets Qt [pre-Malibu terrace] (Kowalewsky, 1990, #11).

17. pre-Malibu Qt with 12' vertical separation in graben (Yerkes and Wentworth, 1965, #1).

18. Boring exposed 30' of bedrock thrust over 25' of older alluvium or terrace deposits [Dume terrace]; low north dip (Escandon, 1983; Kowalewsky, 1990, #9; Kovacs-Byer-Robertson, Inc., 1980d). Significant deep landsliding was revealed in subsequent grading and accounts for at least some of previous observations (JH,pc).

19. Monterey faulted over Qt [Dume terrace] along north-dipping fault exposed in driveway cut (California Geo/Systems, 1987).

20. Trancas thrust over Qt (N76°E, 16°-28°NW in trench, N52°W, 26°NE at about 20' depth in boring) but modified ground surface prevents assessment of recency; Zuma volcanics thrust over Monterey shale in another trench (N42°E, 69°SE) but there was no Qt present and fault was overlain by unfaulted soil; these faults are as much as 200' north of the mapped trace of the Escondido thrust (Kowalewsky, 1990, #10; Kowalewsky, 1989); [Qt is probably on Corral or Dume terrace].

21. Bulldozer cut in bedrock along ridgeline crossed main fault trace (of Campbell and others, 1980) but did not expose obvious fault or major lithologic discontinuity; fault may be 200'-300' to the south (WLC,pc; Kowalewsky, 1990, #8).

22. A topographic break was observed on line with possibly offset soil profile (?), may be irregular weathering of soil/bedrock contact along older shears; Qt [Dume terrace] is faulted (N83°W, 60°N; N70°E, 30-45°N (JJ,pc).

23. Previously mapped fault observed in bedrock excavations; this site merely confirms presence of fault as mapped (Robertson Geotechnical, 1989).

24. Numerous, previously unmapped, north-dipping reverse (?) faults were found within a 1600 foot zone north from Pacific Coast Highway; most displace marine terrace deposits [Dume terrace and older]; observations from trenches and subsequent grading (Mountain Geology, 1987-1991b).

24a. Trenching across mapped fault trace found only deep colluvium with generally unfaulted bedrock to either side (MM,pc).

25. High-angle reverse faults (N86°E, 87°S; E-W, 88°N; N88°E, 90°) in shear zone in Tertiary bedrock, observed in boring between 15.5' and 63' depth (DK,pc; Kowalewsky, 1990, #7).

25a. 250' long trench across mapped trace found unbroken [Dume] terrace/Monterey shale contact; some shears and deformation observed in bedrock (Mountain Geology, 1988); additional work found Dume terrace faulted but soil unfaulted (J. Holt, personal communication, 6/94).

25b. An *inferred* low-angle north-dipping fault was interpreted to displace the base of the soil as exposed in a trench, but a fault was not directly observed and no shears were noted in the soil (Mountain Geology, 1990b); this location corresponds to Dibblee's Latigo fault (Dibblee and Ehrenspeck, 1990-92); fault as mapped by Campbell and others (1970) was presumed to exist beneath the road immediately south of the property.

26. The Solstice fault was observed in trenches; based on trench data, fault location is slightly different from the previously mapped location; fault zone is approximately 60 feet wide with several south-dipping splays; N70°E to N80°W, 60°-70°S; left-oblique displacement indicated by slickensides; fault displaces late Pleistocene colluvial deposits (17,810±240 years old) as well as younger, undated but presumed Holocene, deposits; faulting through up to 25 feet of colluvium accumulated in swale on upper flank of ridge is interpreted to document multiple events, (RSA Associates, 1990; Drumm, 1991; Kowalewsky, 1990, #6; personal trench observations, 1/24/90).

MALIBU BEACH QUADRANGLE (Figure 3c)

27. Detailed studies for proposed Corral Canyon Nuclear Power generating station -four principal north-dipping faults mapped on or near proposed reactor site: Puerco Canyon fault (including lesser faults associated with it) is only fault zone observed to displace marine terrace sands [Corral terrace], but, to the east, does not displace younger deposits estimated to be 8,000 to 10,000 years old (see also localities 28 and 29); Malibu Coast fault dips north at 45° to 80°. Most of the faults are noted to be sub-parallel to bedding. Pervasive shearing in the mudstone of the Trancas formation is interpreted by some workers to indicate distributed displacement while others attribute much of the shearing to shrink-swell processes. (Cleveland and Troxel, 1965 -*faults in green*; Wentworth and Yerkes, 1965; Yerkes and Wentworth, 1965, #8 - *faults in red*).

27a. Continuous 2700' trench, from main trace northward, exposed north-dipping (55°) fault approximately where mapped by Yerkes and Campbell (1980) with a zone of shearing extending about 175' north from the main trace; numerous other sites of bedrock faulting (vertical to steeply north-dipping) were exposed further to the north; data suggested normal, reverse and strike-slip displacements; young soils and colluvium (1,000 to 4,000 years old) were not faulted (Staal, Gardner & Dunne, Inc., 1990)

28. Three trenches reveal 1.5' to 3' vertical separation of the bedrock surface (abrasion platform) across north-dipping faults (north side up) with lesser separation of the overlying terrace deposits; this is identified a the stage 7 terrace (approximately 200,000 years old) but may be younger; mullion (9°SE) on a subsidiary bedrock fault suggests a component of lateral displacement; faults overlain by deposits considered to be Holocene; fault (Puerco Canyon fault) is interpreted to project to locality 29. (Yerkes and Wentworth, 1965, #8; HR#F1).

29. 17' vertical separation (north side up) of Corral terrace (about 200,000 years old) along fault (N65°-85°E, 30°-45°N); note that the strike of this fault (Puerco Canyon fault) does not project along the inferred connection to locality 28; possibly toe of landslide. Qt is not faulted at fault location in the gully to the east. (Yerkes and Wentworth, 1965; HR#F2).

30. Two north-dipping faults with about 11 feet vertical offset of Corral (?) terrace, up on the north, reported in this vicinity (HR#F3).

31. 100'-long trench and shorter trench across mapped trace found a contact between Monterey Formation on the north and intrusive volcanics with sandstone to the south; interpreted to be a non-fault contact; black soil overlies contact without any apparent irregularity (JM,pc & office files).

32. Faulting was not recognized in grading to the west of locality 33 (DG,pc). [faults may be south of grading]

33. Two parallel faults observed in exploratory excavations: at approximately 15' from Pacific Coast Highway a fault dipping 42°N thrusts Monterey Shale over marine sand (displacement of abrasion platform is nearly 6'vertical; soil thickness may be affected); approximately 100' north of Pacific Coast Highway a fault (N60°E to EW, dips up to 57°N) thrusts Monterey Shale over marine sands (up to 2.5' vertical) with splays extending up to base of soil (soil may be thickened downslope of fault); connection of various exposures and interpreted fault pattern varies between geologists. (JJ,pc; HR#F4; Mountain Geology, 1987-1991a); [marine sand is probably associated with the Corral terrace].

34. Trenching through Qt [Corral terrace] and into bedrock for sewage treatment facility (rectangular area) did not find any late-Quaternary faults (Schaefer Dixon Associates, Inc., 1990; personal field observation).

35. Pepperdine University and vicinity: faults shown in different locations according to different references; fault traces of Dibblee and Ehrenspeck (1990-92) and Yerkes and Campbell (1980) shown on Figure 3c; faults as mapped during site-specific investigations and during grading shown on Figure 3d; main trace of Malibu Coast fault observed in grading south of wastewater treatment ponds may have affected soil (Kowalewsky, 1990, #4; JS,pc) but such effect is very tenuous (RH notes, 7/78); shears in fault zone dip north or south at various locations (JS, office files); field records of RH (7/78) show irregular, ambiguous soil/rock contact with many krotovina above steep shear zone in Monterey shale; main (?) trace observed in Marie Canyon includes several north-dipping faults, but near-vertical fault separates Qt [Corral or Malibu terrace] from Sespe Formation and truncates other faults (RH notes, 9/75); about 200' south of main (?) trace, base of Qt [Corral terrace] is offset 50' along fault with 22° to 35° north dip; fault extends up into nonmarine section (Campbell, 1990; HR#F5) – this fault continues as what Leighton and Associates (1989) refer to as the Tennis Court fault; Malibu Bowl fault may not be as continuous as suggested by mapping of Yerkes and Campbell (1980), [compare figures 3c and 3d].

35a. This fault, labeled as Fault "C" by Leighton and Assoc. (1989), is probably the same as a north-dipping fault observed (during grading for wastewater treatment ponds) to place Sespe Formation over Quaternary terrace deposits [Malibu terrace]; nearby placement of Sespe Formation over soil was believed to be possibly related to slumping (notes of CDMG geologists, GB & RH, June-July, 1978); fault observations are not well-located and fault is not mapped east or west of area indicated. See also Figure 3d.

36. Site investigation encompassed by roads on north, west and south. Main trace of Malibu Coast fault zone cuts 200,000 year old [or older] terrace platform, marine sand and part of the overlying non-marine deposits but does not appear to displace higher non-marine Qt estimated to be 75,000 years old; no evidence was found of a northwest projection of the northern fault from locality 37; additional older faults are shown north of the main fault trace (Leighton and Associates, 1989). Also, Birkeland (1972) mentions 47' vertical separation, north side down, across two faults that cut the abrasion platform and the overlying marine deposits. This observation does not correspond, in sense of displacement, to any other observations at this locale and the scale of Birkeland's map does not allow an accurate plotting of his faults. These faults were not evident in subsequent investigation (Richard Lung, personal communication, 1993). See also Figure 3d.

37. Winter Mesa - three north-dipping faults are mapped between the Puerco Canyon fault (to the south) and Pacific Coast Highway based on several trench exposures; although principally vertical separations are recorded, lateral displacement is also assumed. Southern fault dips from 34° to 69° north and has up to 10 feet of reverse separation of the abrasion platform [Corral terrace] but does not displace a probable 35,000 to 40,000 year old relict paleosol. Middle fault dips north at 54° to 70° and has up to 6 inches apparent normal separation of the abrasion platform [Corral terrace], overlying terrace deposits and the base of a 4000 to 6000 year old paleosol near its western end; fracturing extends up into the paleosol; exposure in trench further east shows opposite sense of displacement and correlation between trenches is not certain; fault dies out eastward. Northern fault is a zone about 10 feet wide which dips north at about 62° to 80° and shows up to one foot of reverse vertical separation of a 35,000 year old paleosol but is overlain by 2000 year old soil and was not found in trench across its projection north of Pacific Coast Highway (loc.36). Northern and central faults were presumed active by the consultants. (Converse Consultants, 1986 & 1988; Fall and others, 1987; Rzonca and others, 1991; Kowalewsky, 1990, #5). See also Figure 3d.

38. Malibu Bowl fault - southern trace (blue line), seen in early 1960's, reportedly appeared to offset soil profile (JS,pc), however a post-grading report (Slosson, 1963) makes no mention of this observation; northern trace (red line) characterized by broad zone of faults in bedrock, and possible displacement of marine sand, but disturbed surface prevented younger age determination (HT,pc).

38a. Previous studies (WLC,pc) and preliminary results from ongoing work (EG,pc) suggest that there has been no significant Holocene displacement. There was no detectable offset of a pre-Holocene gravel as identified in a line of borings and cone penetrometer tests which crossed the mapped (but concealed and inferred) traces of the Malibu Coast fault.

39. Fault (E-W, 67°N; N80°E, 48°N) thrusts bedrock over older alluvium; lower part of alluvial terrace deposit is offset; soil and upper alluvial terrace deposits are apparently not offset (Kovacs-Byer-Robertson, Inc., 1980b & 1980c; HR#F7). [Based on elevation, this alluvial terrace appears to be pre-Holocene; Birkeland (1972) and Yerkes and others (1971) show the terrace deposits as late Pleistocene. May be same fault as at locality 42].

40. Borings went through gently northeast-dipping thrust fault affecting basalt and Monterey Formation (Geoplan, Inc., 1980). [Probably same fault exposed at locality 41].

41. Investigations on two parcels defined a gently north dipping (10° to 15°) thrust fault which places basalt over Quaternary terrace deposits [Malibu terrace ?]; no soil offsets were observed (Kovacs-Byer-Robertson, Inc., 1981, 1982, & 1983; Robertson Geotechnical, 1986; HR#F11; Kowalewsky, 1990, #2).

42. Monterey Shale thrust over Corral marine terrace deposits along 45°-60° north-dipping fault, exposed in foundation excavation (Merrill, 1977; HR#F8; Kowalewsky, 1990, #3). [May be same fault exposed at locality 39].

43. High-angle, north-dipping, reverse fault (exposed in retaining wall excavation) displaces marine terrace deposits [Dume terrace ?] (HR#F9; Kowalewsky, 1990, #1).

43a. Cut in slope exposed terrace deposits [pre-Malibu terrace ?] displaced by shallowly north-dipping (39°) fault (Mountain Geology, 1992).

44. Gouge zone up to 18" thick in bedrock; fault oriented N50°W, 53°NE (field observation for this report).

45. Lower Topanga Formation thrust over Qt [Dume terrace ?] along north-dipping fault, based on data from boring (Geoplan, Inc., 1991; HR#F10).

TABLE II
SPECIFIC AERIAL PHOTO OBSERVATIONS

TRIUNFO PASS (Figure 3a)

A - Kelp bed has linear north margin; perhaps controlled by linear change in substrate

B - Back-facing scarp and tonal lineament align with kelp bed

C - Weak south-facing scarps or tonal lineaments

D - Band marked by benches and vegetation contrasts; may be shear zone, shaly interval, or both

POINT DUME (Figure 3b)

E - Gentle slope break on dissected surface remnants coincides generally with fault north of Morning View

F - Atop Point Dume - subtle north-facing scarp with vegetation contrast and tonal lineament is near mapped fault segment (Point Dume fault).

G - At Ramirez Canyon - vegetation lineament near mapped fault

H - At locality 26 - prominent sidehill-bench, possible landslide

MALIBU BEACH (Figure 3c)

I - The continuation of the Solstice fault is apparent as a strongly developed sidehill bench.

J - V-shaped depression on ridgetop has inward-facing scarps and a local closed depression along one side; looks like ridgetop spreading feature.

K - Marie Canyon & Pepperdine campus - A strong tonal lineament and/or sidehill bench indicates main trace of Malibu Coast fault in bedrock but fault is not visible where it should cross the drainage to the east (probably covered by alluvium) or in Quaternary terrace deposits further east; this fault expression is probably erosional. A tonal lineament and possible subtle south-facing scarp may coincide with southern blue fault trace (of Dibblee and Ehrenspeck, 1990-92) or may be old shoreline angle; another short tonal lineament is a possible projection of the Tennis Court fault (of Leighton, 1989). [Correlation to faults is uncertain -- fault locations are not precise since southern trace of Dibblee appears to be the same as the Tennis Court fault; see discussion of locality 35 on page 30]. See also Figure 3d.

L - Break in slope coincides roughly with the Puerco Canyon fault, but may merely be degraded seacliff associated with lower marine terrace.

M - Various tonal and vegetational lineaments near locality 37; the only features possibly related to the faults are a short linear drainage along the northwestern projection of the northerly of the three faults and a possible arcuate, north-facing scarp or clump of vegetation which may be related to the western end of the middle fault; curvature of this vague scarp, however, would be more appropriate to a south-dipping structure.

N - Tonal lineament at civic center is near a concealed fault trace. [Studies in this vicinity (loc.38a) found no evidence for displacement of Holocene deposits, but data were not conclusive].

O - Features across late Pleistocene surfaces are near, but south of, mapped faults: subtle lineament along bluff face marked by vegetational contrast and possible slope break (probably marks lower terrace deposit contact); southern margin of subtle east-west linear welt, which appears just to the north, may correspond to resistant bedrock faulted against Qt as observed at locality 42.

TABLE III
Summary of Conclusions and Recommendations for Segments of the Malibu Coast Fault Zone Relative to Zoning Under Alquist-Priolo

FAULT SEGMENT	SUMMARY OF ZONING CRITERIA		ZONING RECOMMENDATION[1]
	RECENCY	DEFINITION	
MALIBU COAST FAULT (main trace)			
west from Trancas Canyon	late Quaternary	poor to moderate	no
Trancas Cyn. to Ramirez Cyn. (trace of Campbell et al, 1970)	late Quaternary (?)	poor to moderate	no
Trancas Cyn. to Ramirez Cyn. (trace of Dibblee & Ehrenspeck, 1990-92)	late Quaternary	poor	no
Ramirez Cyn. to Solstice Cyn. (trace of Campbell et al, 1970)	late Quaternary (?)	poor to moderate	no
Solstice Cyn. to Malibu Creek	pre-75,000 ybp	poor to moderate	no
Malibu Creek to Carbon Beach	late Quaternary	poor to moderate	no
Southern trace - Corral Cyn. to Marie Cyn. (main trace of Dibblee & Ehrenspeck, 1990-92)	Quaternary (?)	poor to moderate	no
MALIBU BOWL FAULT (part from Marie Canyon to Malibu Creek)	late Quaternary (?)	poor	no
SOLSTICE FAULT	Holocene (in part)	poor to well	**zone**
LATIGO FAULT	late Quaternary (?)	moderate	no
PUERCO CANYON FAULT	late Quaternary pre-Holocene (?)	poor to moderate	no
ESCONDIDO THRUST			
Trancas Cyn. to Walnut Cyn.	late Quaternary	poor	no
Walnut Cyn. to Escondido Beach (Ramirez fault of Dibblee)	late Quaternary	poor	no
PARADISE COVE FAULT	pre-late Quaternary (?)	poor; inferred	no
POINT DUME FAULT	pre-late Quaternary (?)	moderate to well	no
OTHER CRITICAL SITES			
Locality 33	late Quaternary	poor; limited extent	no
Locality 37 (GM site - two faults)	Holocene	moderate; limited extent	**limited zone**

1. Recommendation is based on how well the data meet the established zoning criteria which require that a fault be sufficiently active and well defined (Hart, 1990). "A fault is deemed sufficiently active if there is evidence of Holocene surface displacement along one or more of its segments or branches. •••• A fault is considered well-defined if its trace is clearly detectable by a trained geologist as a physical feature at or just below the ground surface."

AERIAL PHOTOGRAPHS USED

Fairchild Aerial Surveys Flight C300 1928
scale - 1:18,000 b/w 7x9
frames

H1 to H3	H83 to H88
H7	J14 to J16
H9 to H11	J33 to J34
H16 to H17	J54 to J57
H24 to H25	J77 to J80
H33 to H35	J99 to J101
H44 to H46	J118 to J120
H56 to H59	J138 to J141
H69 to H74	

U.S. Department of Agriculture
scale - 1:20,000 b/w 9x9

frames	AXI-1K-90 to 195	12/13/52
	AXI-11K-166 to 168	1/14/54
	AXJ-1K-2 to 4, 13 to 15, 22 to 25, 40 to 44, 48 to 53, 73 to 77, 104 to 106	11/ 3/52
	AXJ-2K-1 to 3	11/ 3/52
	AXJ-14K-37 to 40	11/19/53

U.S. Geological Survey Flight GS-EM 1947
scale - 1:24,000 b/w 9x9

frames	1-149 to 1-164	8/15/47
	6-08 to 6-18	8/21/47

U.S. Geological Survey USAF 041V 4/2/1970
scale - 1:140,000 b/w 9x9
frames 88 to 91

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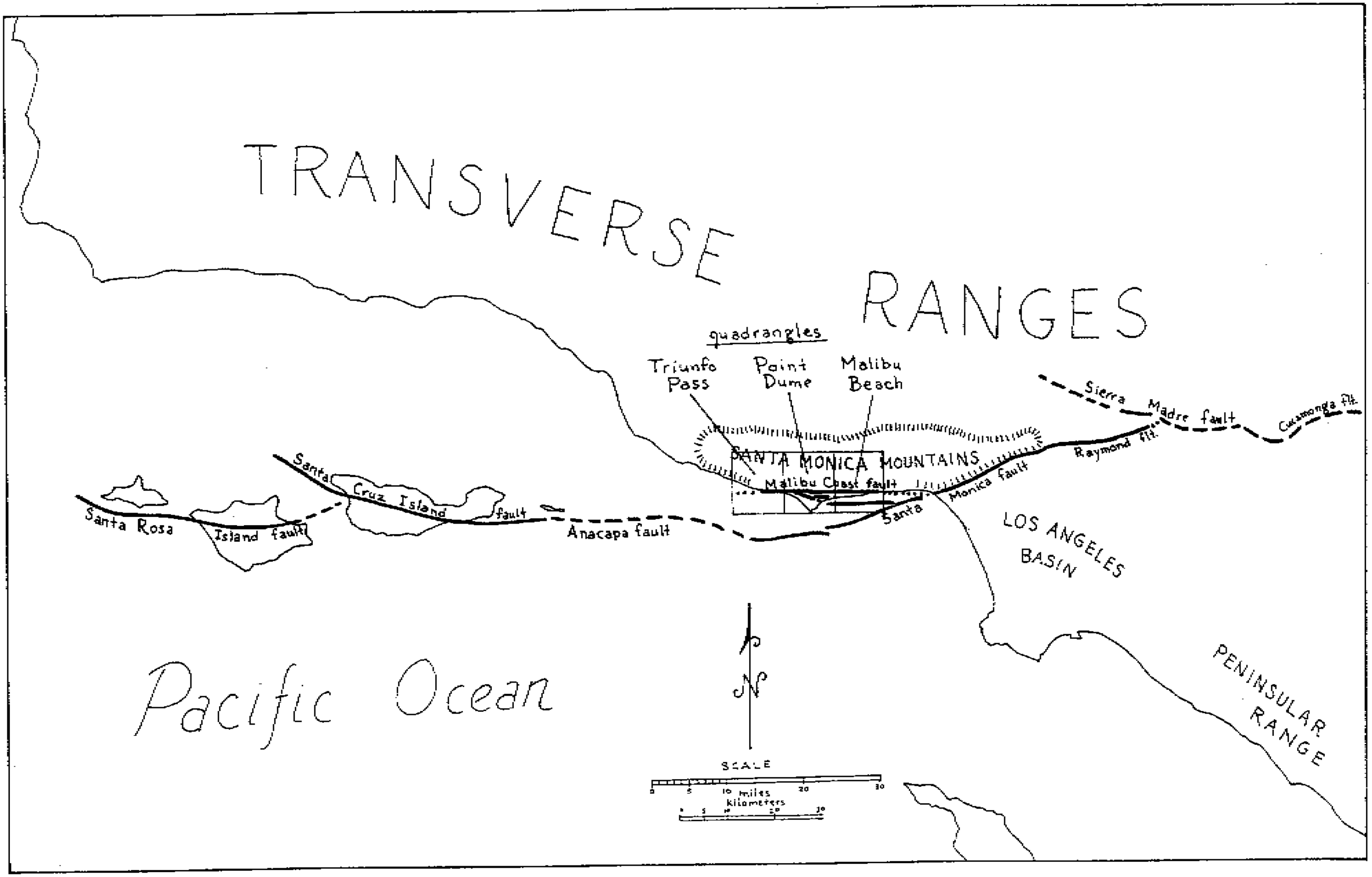


Figure Ib (FER-229). Regional setting -- Malibu Coast fault zone and related faults (modified from Jennings, 1975).

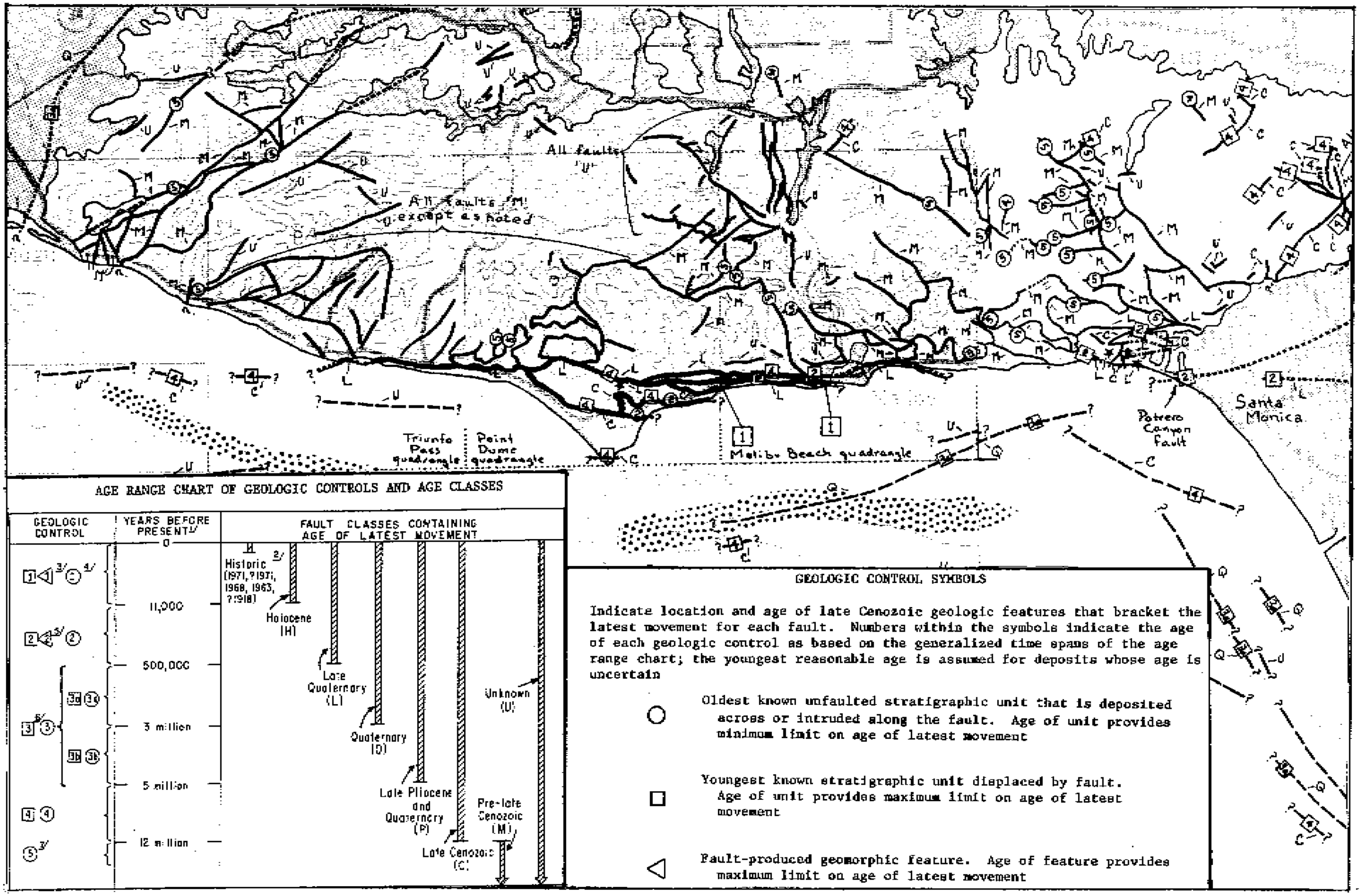


Figure 2a (FER-229). Recency of faulting along the Malibu Coast fault zone and related faults (modified from Ziony and others, 1974, to show two recently identified localities of Holocene faulting). scale - 1:250,000

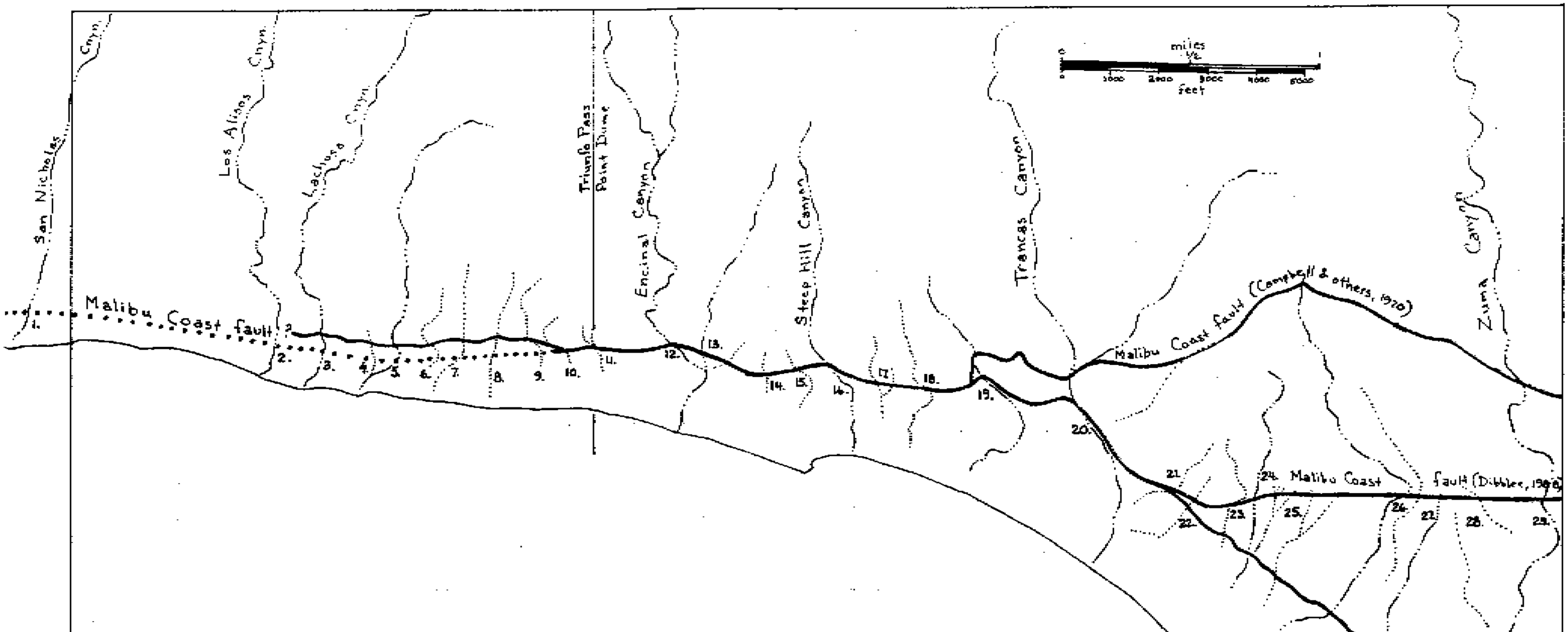


Figure 4b (FER-229). Drainage patterns: western part of the Malibu Coast fault zone, Triunfo Pass and Point Dume quadrangles.

ephemeral drainages
other minor drainages
faults
annotations (see below)

1. No offset of Nicholas Canyon in past 120,000 years.
2&3. No offset at fault, but unrelated left-deflection occurs upstream.
4. No deflection of minor drainage.
5&6. Ambiguous effect: possible left detection at northern fault and right detection at concealed trace.
7. Right deflection of minor drainage.
8 No deflection of minor drainage.
9, 10 &11. Left deflection of minor drainages.
12. Possible left deflection of Encinal Canyon
13. No deflection.
14 & 15. Left deflection of minor drainages.
16. Possible left deflection of Steep Hill Canyon.
17. Left deflection of one of two minor drainages
18. Left deflection of minor drainage.
19. Possible left deflection along Escondido thrust.
20. Possible left deflection of Trancas Canyon along Escondido thrust.
21. Right deflection of minor drainage.
22. No deflection of minor drainage.
23. Right deflection of minor drainage.
24. No apparent deflection.
25. Several minor drainages may have been offset from 24.
26. Possible right deflection of two parallel drainages.
27. Possible beheaded drainage from 26.
28. Possible beheaded drainages.
29. No deflections apparent to Zuma Canyon, although beheaded drainages may exist to the east (see Figure 4a).

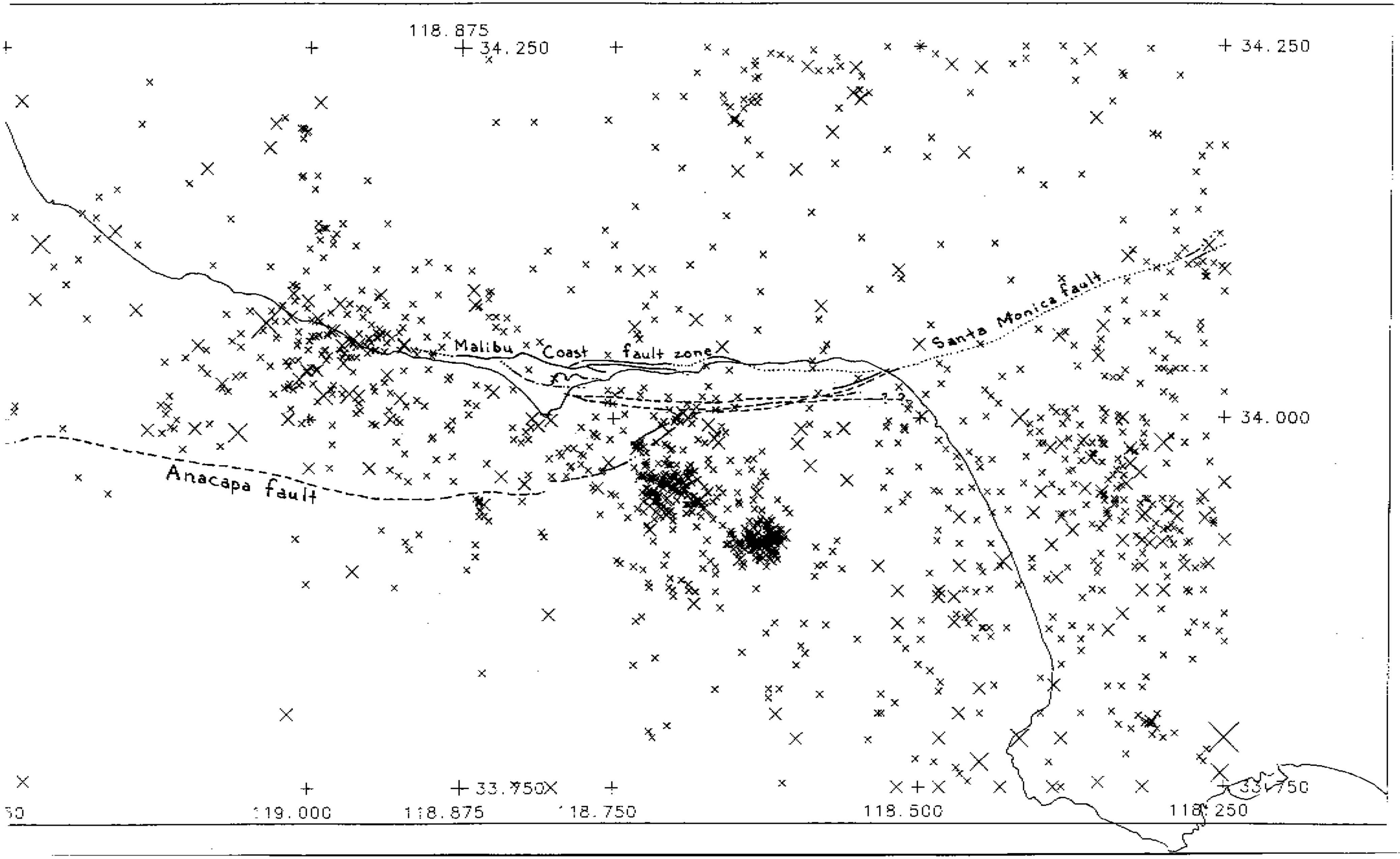


Figure 5a (FER-229). Regional seismicity for the period from 1932 to March 16, 1989. Shown are earthquakes of M1.0 or greater. (from California Institute of Technology, 1989) (faults from Jennings, 1975; Yerkes and Lee, 1979; Greene and Kennedy, 1986)

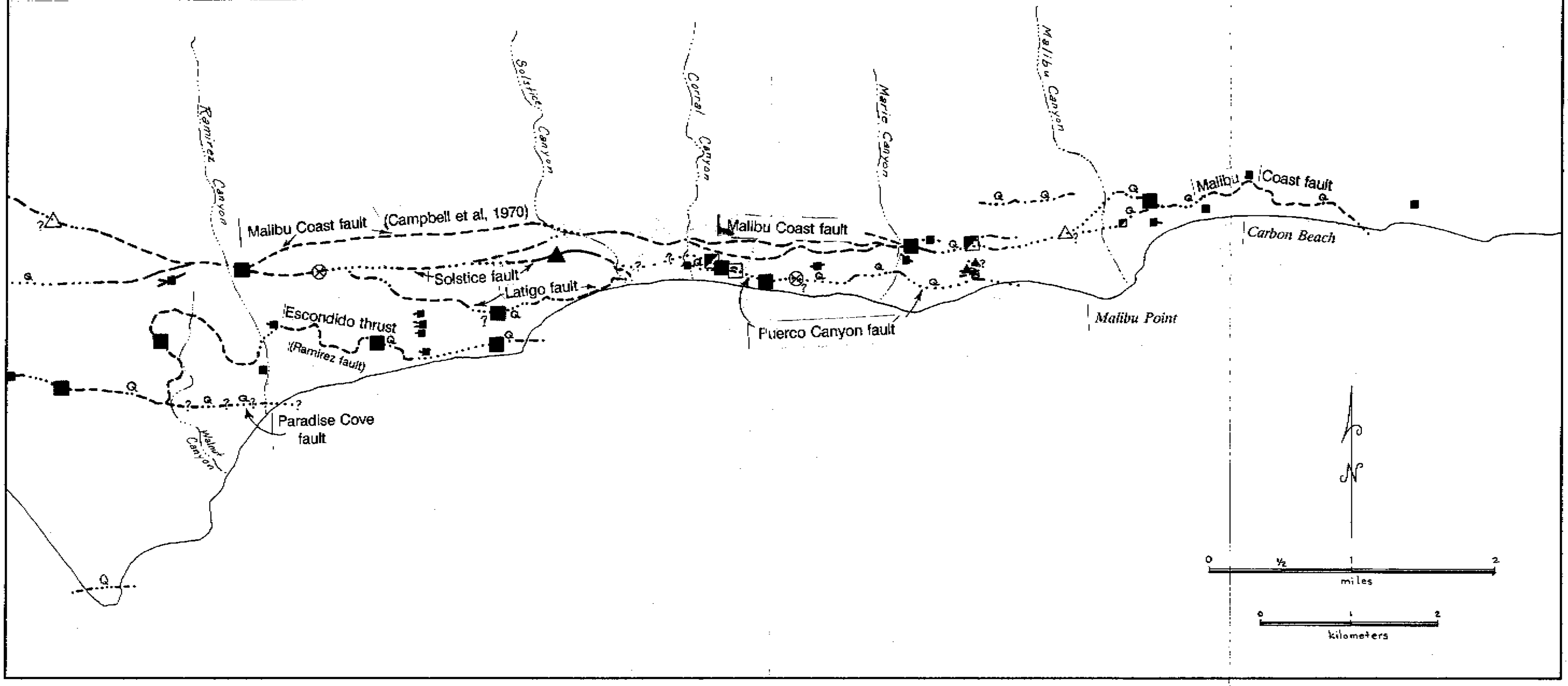
Figure 2c (FER-229) - Summary map (east from Point Dume) showing main fault traces and all evidence of late Quaternary activity. Late Quaternary activity of faults is not known except where indicated. (Based principally on Table I with additional data from map sources as indicated on Figures 3a,b & c).

EXPLANATION

main fault traces, dotted where concealed; Q indicates fault is shown as concealed by late Quaternary terrace deposits, based on mapping of others

based on site specific investigation (see Table I):
- Holocene deposits are displaced
- Holocene deposits are not displaced
- late Pleistocene terraces (stage 5 or 7) are displaced but Holocene is not displaced
- late Pleistocene terraces are displaced
- late Pleistocene terraces are not displaced
- fault not found at mapped location

large symbol used for data along main faults
small symbol used for data along minor faults
data queried (?) where equivocal



EXPLANATION

main fault traces, dotted where concealed; Q indicates fault is shown as concealed by late Quaternary terrace deposits, based on mapping of others

based on site specific investigation (see Table I)

- ▲ Holocene deposits are displaced
- △ Holocene deposits are not displaced
- ◩ late Pleistocene terraces (stage 5 or 7) are displaced but Holocene is not displaced
- ■ late Pleistocene terraces are displaced
- □ late Pleistocene terraces are not displaced

large symbol (□△) used for data along main faults
small symbol (■▲) used for data along minor faults
data queried (■?) where equivocal

Figure 2b (FER-229) - Summary map (west from Point Dume) showing main fault traces and all evidence of late Quaternary activity. Late Quaternary activity of faults is not known except where indicated. (Based principally on Table I with additional data from map sources as indicated on Figures 3a,b & c).